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Advanced Base Materials for Industrial Textiles: Progress and Countermeasures

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Abstract: The textile industry is a pillar of China's national economy, and advanced base materials for industrial textiles are critical for China's textile industry. In this article, we focus on three types of advanced base materials that are in wide demand by the textile industry considering the key technologies for material manufacturing, material production modes, and industry status; these materials are nonwoven fiber materials, textile structural materials, and textile composites. Subsequently, we analyze the development status and trend of advanced base materials for industrial textiles in China and abroad, summarize the main problems faced by China in this field, and expound the key tasks and core technologies for their development in China. To promote the development of these materials, China should strengthen the overall planning for the industry, improve the national system for supporting science and technology innovation, and foster a group of specialized and excellent enterprises to participate in international competitions.

Keywords: nonwoven fiber materials; textile structural materials; textile composites; research progress; key tasks

1 Introduction

China has entered the stage of high-quality economic development. At present, the textile industry is in a key period of transformation from the old growth mode to the new growth mode, and from large to strong development. Facing the increasingly severe challenges of resources and environment, the challenges of the world's new industrial revolution and new scientific and technological revolution, and the construction of strategic emerging industries [1–3], the textile industry maintains the trend of sustainable development, from leading the total scale to leading in scale, quality, efficiency, and scientific and technological level, to ensure the high-quality development, transformation, and upgrading of China's textile industry, which is related to the stability and prosperity of the country's economy and society. Textile materials with industrial textiles as the main body are the foundation and key to the development of China's textile industry.

Textile materials have a large output and wide range of applications, and they belong to basic materials. With the continuous improvement of market demand, the proportion, technical indexes, and international competitiveness of advanced basic materials in the field of textile materials in China are constantly improving [4]. Meanwhile, although China has made remarkable achievements in advanced base materials for industrial textiles, it faces equally important problems [5–6]. The homogeneity of general fiber materials is prominent, and the functionalization, high performance, greening, and high quality of products are in urgent need of improvement. In-depth research is lacking on the application technology of new textile materials with high performance and function, and relevant standards and technical specifications need to be established and improved. Industrialization results of new materials with significant innovation and disruptive technology are lacking. The integrated innovation ability is weak, the

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combination with the industrial chain is not tight, and sophistication and informatization of equipment is not high.

On the basis of the connotation of advanced basic materials for textile structure, this paper analyzes nonwoven materials, textile structure materials, and textile composites, and presents current key material varieties, research status, and problems. This article mainly discusses the key tasks and technologies for the future development of advanced basic materials for industrial textiles in China, and it offers planning suggestions for strengthening industrial development to provide a theoretical reference for the material technology progress of the textile industry in China.

2 Research background of advanced base materials for industrial textile

2.1 Basic characteristics

Advanced basic materials in the textile field usually have the following characteristics: (1) excellent physical and mechanical properties and quality of the material, such as strength, modulus, uniformity, and performance stability; (2) physical and mechanical properties that meet application requirements, along with the endowment of new functions through physical and chemical means, such as molecular modification and functional powder addition modification to provide the material with flame retardant or antibacterial functions; (3) environment friendliness of the whole lifecycle, such as biological fibers whose raw materials from natural renewable resources or recycled resources, polylactic acid fibers with controllable degradation, and polyester fiber with low-temperature dyeing; and (4) the ability of digitalization, flexibility, and intelligence of the manufacturing process to improve the differential/functional manufacturing efficiency and product quality of textile materials, and the reduced energy consumption and material consumption in the production process. For example, three-dimensional structural materials based on automatic weaving technology have good material properties and quality uniformity.

With the development of the industry, many key strategic materials and frontier new materials developed in the textile field have gradually become new advanced basic materials.

2.2 Macro situation

The textile industry is the pillar industry of China's national economy and is an important industry for people's livelihood and the industry with international competitive advantage. The advanced base materials of a textile structure take chemical fiber and industrial textile as the main body, and serve as the foundation and key of the development of the textile industry in China. The total amount of fiber processing for all kinds of advanced basic materials of textile structure in China is 5.43×10^7 t, of which the output of chemical fiber is more than 4.7×10^7, accounting for more than 70% of the world's chemical fiber output. Textiles used in new energy, aerospace, medical and health, environmental protection, and other industries account for 26.9% of China's fiber processing [7,8].

With the development of social economy, resource depletion and environmental problems become increasingly prominent practical contradictions. This situation prompted the textile industry to identify textile fiber materials as important basic and engineering materials, which the country also included in the development plan of emerging industries. In the aspect of advanced basic materials of textile structure, China should strive to produce a number of original innovation achievements with independent intellectual property rights, which constitute the mechanism of high-efficiency transformation of scientific and technological achievements, and form innovation ability to support the lasting development of the industry [9]. Other objectives include promoting the proportion of high-end products in key areas of our country and ensuring that the environment friendliness and intelligentization of textile materials ranks high internationally, thereby leading the stable and healthy development of the textile industry [10–12] to meet the requirements of a prosperous society and strategic emerging industries, and fulfill other major needs.

2.3 Main categories

On the basis of the key technology of material manufacturing, considering the factors of material production and industry status, this paper focuses on three types of advanced base materials for industrial textiles: nonwoven fiber materials, textile structural materials, and textile composites (Table 1).

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Table 1. Main categories of advanced industrial textile structure materials.

Name	Meaning and characteristics	Key varieties	Application field
Nonwoven fiber materials	Nonwoven fiber material is a porous fiber network medium material that is directly connected by fibers, which is the key material category of industrial textiles. The basic structural unit is a network structure composed of three-dimensional directional or randomly arranged fibers, which is formed by the friction, binding, entanglement, and adhesion between the fibers.	Bicomponent spunbond-spunlace nonwoven materials, high efficiency and low resistance and durable electret nonwoven air filter material, multi-die melt spinning composite nonwoven, high-temperature-resistant nonwoven filter material, micro-nanofiber composite nonwoven filter material and nonwovens used for flushable wet wipes, etc.	Medical and health, environmental protection, transportation, geotechnical construction, aerospace, agricultural technology, daily life, etc.
Textile structural materials	A fiber aggregate material in which interdependent fibers are assembled and arranged through spinning and weaving processes. According to the different processing technology, it is divided into thread/rope/belt, woven fabric (plain, twill, satin, jacquard), knitted fabric (warp, weft), braided fabric, etc.	Carbon fiber fabric, three-dimensional braided materials, stab-resistant materials, braided geotechnical materials and high-strength ropes, etc.	Reinforced structure, human body protection function structure, smart textile structure, medical textile structure, geotechnical structure, high-strength thread/rope (cable)/belt, etc.
Textile composites	A composite material with textile material as structural reinforcement and matrix material divided into rigid and flexible structure composites. The former is usually made of high-modulus fibers, and the latter includes at least two parts of reinforced structure and coating structure [13].	Glass fiber-reinforced composites, carbon fiber-reinforced composites, aramid fiber-reinforced composites, silicon carbide fiber-reinforced composites, functional flexible canopy materials, lightweight high-strength airship envelope skin materials and medical mesh structure composite patch materials, etc.	Aerospace, automobiles, ships, safety protection, geotechnical construction, wind turbine blades, leisure and entertainment, etc.

3 Development status of advanced base materials for industrial textiles in China and abroad

3.1 International development status

3.1.1 Nonwoven fiber materials

From 2012 to 2017, the North American nonwovens industry experienced strong growth (the average annual growth rate exceeded 3.7%), and the average annual growth rate from 2018 to 2022 is expected to remain at 3.6% [14]. Dozens of new production lines have been added in North America, including needle punching, thermal bonding, spunbond, wet, spunlace, and other processes. Nonwovens technology has been diversified, involving filtration, transportation, absorbent sanitary materials, wiping, and other fields of application. For example, the demand scale and growth rate in the terminal field are increasing, especially nonwoven materials for absorbent sanitary products and for transportation [14].

The production process of nonwoven materials is developing toward the direction of multiprocess combination, such as bicomponent, special-shaped cross-section spunbond technology, composite spunbond nonwoven technology, and its integration with subsequent processes. The development trend of nonwoven equipment is large, high yield, and high speed; the single-line output of the production line will continuously increase and gradually move toward intelligence; equipment becomes more energy-efficient while the proportion of waste recycling and reuse gradually increase. The nonwoven material production line is developing in the direction of modularity, versatility, and differentiation. At present, a modular design is typically adopted to meet the requirements of flexible combination of production lines [15].

The development focus of nonwoven machinery is as follows: online compound molding of multiple processes and hybrid nonwoven equipment, microfiber and other super absorbent material preparation equipment, a complete set of production lines for elastic nonwovens, multifunctional nonwoven additive equipment and transmission systems. The online automation level and online detection control ability of production lines are expected to improve, special fiber processing equipment and production lines are expected to be developed.

3.1.2 Textile structure materials

Carbon fiber fabric is one of the important textile structural materials. The carbon fiber fabric produced by Toray of Japan, Forrisio International Group in the UK, Zoltek of the United States, and SGL Carbon Group of Germany has excellent mechanical properties and is widely used in the automotive industry, wind power, aerospace, mechanical engineering, medical equipment, sports equipment, and safety fields.

Three-dimensional braided materials involve a number of advanced technologies represented by the textile and forming of fiber stereoscopic fabrics. Since 1985, US National Aeronautics and Space Administration has implemented the advanced composite technology program, with an average annual funding of about 200 million USD. Other industrial countries have also conducted systematic research on three-dimensional woven composites. Functional integration, structure and function integration, and low-cost and rapid three-dimensional fabric forming are the development focus of three-dimensional fabric technology [16].

The research and development of stab-resistant products has become a hot spot. Examples of such products are the Kevlar Correctional stab-resistant vest of DuPont, the Turtle Skin MFA stab-resistant vest of Warwick Mills, the anti-penetration vest of Criminology International, the woven stab-resistant fabric from the University of Delaware, soft stab-resistant clothing from the Genitex laboratory in France, and concealed stab-resistant clothing for office staff by Aseo Europe in the UK.

Grid structure geotextile is mainly used for drainage ditch, dam or chimney filtration, bridge body protection, railway structure, coastal protection without intermediate layer, artesian water pressure interception, vertical ground, asphalt road, inclined surface, and embankment base reinforcement. In recent years, special machines developed in Germany have been able to produce multiaxial structural geotextiles and new-type pre-oriented structural fabrics.

High-strength ropes mostly use aromatic polyamide fibers (such as Kevlar) and ultra-high molecular weight polyethylene fibers (such as Spectra, Dyneema), which are made of multiple strands of yarn or threads. In the 1990s, Spectra (U.S.) and Dyneema (Netherlands) were successfully used in parachute manufacturing. At present, they are widely used in large hoisting, aircraft carrier ropes, and marine protective rope nets.

3.1.3 Textile composites

The applications of rigid structure composites mainly include aerospace, wind turbine blades, automobiles, and ships. More than 50% of the composite material is used by the new generation of large passenger aircraft (Boeing 787, A350XWB of Airbus). Driven by low-wind-speed land and sea wind fields, the large-scale development trend of wind turbine blades is particularly obvious, thereby prompting the continuous rapid increase in the use of advanced carbon fiber composites.

Rigid functional composites have the property of designability, and composites with rigid and functional diversity can be obtained through the design of different component materials. The sound-absorbing bottom plate developed by Hof Company of Germany using fiber orientation technology can greatly reduce the air resistance and negative impact of vehicles in motion and has been applied in the new generation of models. Kerr-MeGee Corporation, Johns Manvile Corporation, SGL Carbon Group, and Stuttgart University have also conducted a large amount of research on rigid functional composites.

Rigid structure-functional integrated composites are used for products that have a high requirement for material bearing capacity and some functions. For example, carbon/carbon composites are the preferred materials for large solid rocket throat liners, engine nozzles, diffusion sections, and end caps. Carbon/phenolic composites are used as important ablation-resistant materials for high-speed aircraft, such as manned spacecraft return tanks, advanced fiber-winding composite rocket shells, rocket nozzles, and re-entry protection shells. Rigid structure-functional integrated composites are also widely used in space vehicles that are subjected to complex space environments and long-term service conditions.

Planar membrane structure flexible composites are mainly used in building membrane structures, canopy materials, and flexible advertising materials. Most of the early forms are polyester fabric composites. High-performance fiber structure flexible composites have emerged in recent years, such as Kevlar, thermotropic liquid crystal polyaryl ester fibers (Vectran), and polyp-phenylene-braced benzobium-benzazole fibers (PBO). The canopy material is the main product of the flexible composite material of plane membrane structure. At present, chemical fiber materials are still coated with PVC or polyethylene. The material variety is diverse, with rapid application development and a relatively stable market.

The typical application object of three-dimensional inflatable flexible membrane structure materials is the envelope skin material of floating air vessels. At present, the skin material system of floaters abroad has been basically formed. Representative research projects include the High-Altitude Airship program, the Sensor and

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Structure Integration project, and the High-Altitude Sentry project of the United States; and the Stratospheric Platform project of Japan. Research has also been conducted by relevant scientific research institutions and enterprises in Europe, Russia, South Korea, and Israel. Japanese enterprises have obvious technical advantages in the skin material of adjacent space floaters and have obtained more applications of US and European floaters.

The mesh structure flexible composite material is mainly used in medical patch materials and tissue engineering flexible structures, and it is mainly available in the form of composite patch. Most patches have a large mesh structure, which is conducive to the growth of the tissue and has good extensibility, thereby improving the comfort of people during activities. The related foreign research has been relatively mature, such as Parietex composite patch, ProGrip patch, Proceed patch, and Vypro II patch. The Bard 3DMax patch has a three-dimensional structure, which can be predetermined according to the design size, without cutting and other fixtures.

3.2 Domestic development status

3.2.1 Nonwoven fiber materials

The development of the nonwoven material industry in China has a brief history but a rapid speed. The national output surpassed Japan for the first time in 1999, reaching 3.2×10^5 t. In 2009, it exceeded North America and Europe for the first time, reaching 2.409×10^6 t, ranking first in the world. According to statistics [15,17], the world's nonwoven production in 2016 was about 1.24×10^7 t, of which China's nonwoven production was 5.354×10^6 t, accounting for about 43% of the global output. The proportion is equal to that of Europe, North America, and Japan combined. As a veritable nonwoven material production country, China is involved in various processing methods such as spunlace, needle punching, spunbonding, meltblown, chemical bonding, thermal bonding, airlaid, and wet methods. Chemical bonding accounts for 49%, the needle punching method accounts for 23%, and the spunlace method nonwoven material accounts for 10% (the relative proportion is equivalent to the United States and Europe).

In terms of regions, nonwoven production in China is mainly concentrated in the eastern coastal areas, accounting for 70.2% of the country's total and still maintaining a steady growth. In the central and western regions, Hubei's output reached 4.08×10^5 t. Henan, Sichuan, and other places are also involved in nonwoven production. Although the output is small, it has maintained a momentum of rapid growth. China's major nonwoven materials production provinces are Shandong (21%), Zhejiang (19%), Jiangsu (10%), Hubei (9%), and Fujian (8%), accounting for 67% of the country's total output. Shandong's output advantages are outstanding. Its production capacity has expanded significantly due to its rapid investment in geotechnical and waterproof membrane base fabrics. Moreover, many traditional textile companies in Shandong have shifted to spunlace nonwovens, thus resulting in a rapid growth of the production capacity. The growth rate of nonwoven production in provinces such as Zhejiang, Fujian, and Anhui is around 15%.

3.2.2 Textile structure materials

China's production of carbon fiber fabric has developed rapidly in recent years. Zhongfu Shenying Carbon Fiber Co., Ltd. is the third enterprise to realize industrialization of high-performance dry-jet wet-spinning carbon fibers after Toray Industries of Japan and Hexcel Corporation of the United States. It has a market supply capacity of 100-ton T800 carbon fibers. The performance index of the developed SYT55 high-strength medium-modulus carbon fibers has reached the international advanced level and can replace imports. A group of enterprises represented by Guangzhou Kingfa Carbon Fiber New Material Development Co., Ltd. produce carbon fibers and carbon fiber fabrics with excellent properties and complete specifications, which are widely used in mechanical, sports, construction, aerospace, and other fields.

Domestic research and development in the field of three-dimensional braided materials began in the 1970s, which was first implemented by Nanjing Fiberglass Research and Design Institute Co., Ltd. Tiangong University is one of the earliest institutions to conduct three-dimensional braiding research in China. In 2002, it developed the first domestic double-axis knitting equipment for weft knitting. In 2014, it developed electronic jacquard control multilayer opening technology and constant tension active continuous multilayer let-off technology and successfully developed the first three-dimensional knitting equipment in China. In addition, a group of emerging enterprises represented by Jiangsu Tianniao High Technology Co., Ltd. supplemented the imported equipment of three-dimensional fabric weaving, partially realized the large-scale mass production of carbon fiber composite materials, and successfully applied the products to railway locomotive accessories and aircraft brake preforms.

In the field of stab-resistant materials, relevant research work in China started only in 2000 and has formed a certain scale at present. A group of enterprises represented by Beijing Shiqi Fibre Weaving Co., Ltd. mainly produce flexible stab-resistant clothing, which integrates cutting, anti-piercing, anti-terrorism, and anti-ballistic functions, and is widely used in civil and military police human protection products. Some companies are also conducting technical research on flexible stab-resistant clothing. The related products, such as light soft stab-resistant clothing, ballistic stab-resistant clothing, and life-saving body armor, fill the gaps in domestic military and police equipment.

In the field of grid structure geotechnical materials, the product market is closely related to the construction of the national infrastructure. For example, in 2017, the scale of new investment in China's railway industry was 356 billion CNY, the total investment in fixed assets in highway construction was 2.11625 trillion CNY, and the investment in water conservancy was 717.6 billion CNY, coupled with the promotion of the construction of the Belt and Road. It has greatly promoted the rapid development of China's geotechnical and construction textile industry [17].

In the field of high-strength ropes, practical applications have been implemented in many fields. A group of companies represented by Yangzhou Jushen Rope Co., Ltd., as a domestic professional manufacturer of chemical fiber ropes and nets, have realized the arbitrary design of multistrand and multilayer braided structures, and solved the problem of unlimited length braided ropes and unlimited lengths. More than 3000 kinds of rope and net products exist, and all kinds of high-end rope, net, thread, and belt products are widely used in aerospace, ships, marine engineering, safety protection, fire rescue, outdoor sports, transportation, and other fields.

3.2.3 Textile composites

Rigid textile structural composites, as advanced basic materials, strategic key materials, and frontier new materials, are included in the New Material First Batch Application Demonstration Directory of the Ministry of Industry and Information Technology. These composites are carbon fiber composite wire, automobile carbon fiber composite material, wind power carbon fiber composite material, and aviation carbon/carbon composite material. The projects related to the textile composite field in the technical roadmap of the key areas of China Manufacturing 2025 include lightweight automotive body composites, high-performance carbon fibers and their composites, high-performance para-aramid fibers and their composites, and other high-performance fibers and their composites.

In addition to the commonly used carbon fiber and glass fiber, rigid functional composites also include aramid III and its composites, which have been widely used in advanced aircraft and new ships. China developed composite radome and mine shell in the late 1980s and developed composite mast and superstructure for large ships in the 1990s. Compared with foreign countries, the research and application of ship composite materials in China is still in the development stage, and the future industrial space is large.

In the aspect of rigid structure-functional integrated composite materials, a number of institutions, such as Nanjing Fiberglass Research and Design Institute Co., Ltd. and Tiangong University, began to develop carbon fiber composite engine shell in China in the 1980s. Preform is an important manufacturing link of carbon/carbon composites, which supports the formation of composite materials with the functions of structural rigidity, high temperature and heat insulation, and ablative resistance.

In plane membrane structure flexible composite materials, domestic high technology is low, high value-added products are few, and the technology research and development ability need to be strengthened. With Shanghai Shenda Kobond New Materials Co., Ltd. as the representative of a number of enterprises, with a better tarpaulin material production professional basic level, the production of PTFE film and PVC film is close to the international advanced level, but a gap exists for some high-end equipment membrane materials, and the application of product service research and solutions is not perfect. According to the statistical analysis of China Nonwovens & Industrial Textile Industry Association, as a large category of flexible composite materials in 2017, canopy materials account for about 16.6% of the total processing capacity of industrial textile fibers in China [8].

In the aspect of three-dimensional inflatable flexible membrane structure material, the domestic research and development level is low, thereby being unable to produce three-dimensional large spacing fabric efficiently. Developing special production equipment with high speed and intelligence for super thickness spaced fabric is crucial.

In the field of mesh structure flexible composites, domestic high-end hernia patch (hernia repair) is still imported to some extent. The price and actual effect of domestic hernia patch are good, and the number of clinical patch production enterprises is increasing gradually. Although the domestic patch can meet the basic clinical application, the innovation of the product is not enough; it is made of imported substrate, and a gap still exists with the international first-class level.

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4 Problems faced by advanced base materials for industrial textile in China

4.1 Common problems in the industry

The protection of intellectual property rights in the industry of advanced base materials for industrial textile needs to be strengthened so that enterprises can enjoy the market benefits brought by intellectual property rights for a certain period of time and encourage them to innovate. However, crucial contradictions still exist between low illegal costs and high rights protection costs in the industry. Such issues are still difficult to solve in a short period of time [18].

The dilemma of technological innovation is critical. More enterprises value economies of scale while ignoring the breakthroughs of high-tech products. As a result of the decline in profits, investing the necessary resources for the development of high-end products is difficult, the development capacity of new products is weak, and high-tech products cannot meet the market demand.

Compared with the development speed of the industry, the basic research capability of the industry is weak and the quality of professional and management personnel training is poor, thereby restricting the healthy development of the industry and the progress of science and technology.

Industrial textiles are extensively used in a wide range of fields, and similar products have different technical requirements in different application fields, but the industry lacks the overall design of the standard system [19]. As a result, the relevant standards of industrial textiles have not been unified, and convergence and coordination between the existing standards are insufficient.

4.2 Problems in technology and product

Nonwoven fiber materials are facing the monopoly of foreign advanced technology. Driven by macroeconomic policies and a strong domestic demand market, the nonwoven filtration industry in China has made considerable progress in the past 10 years, but because it has been limited by the late start of the industry, insufficient attention has been paid to the technical research and development of filter materials, related raw materials, gradients molding, membrane compounding, detection, and simulation theory. The industry and its products are far from the advanced level of foreign countries, and many high-performance filter materials rely on imports due to the industry's inability to produce them [17,19]. In terms of the standard system and evaluation system, the problem of inconsistency in the technical indicators and testing method standards of related products is significant, resulting in poor connection between product standards and final product application standards and the lack of effective regulatory oversight of product quality. At the product level, the technology of domestic enterprises is single and the phenomenon of product homogeneity is evident. With microfiber leather taken as an example, domestic companies basically adopt the indefinite island technology (introduced by Wanhua Chemical Group Co., Ltd. from Japan Kuraray Co., Ltd.), and the similarity of production processes will inevitably lead to product homogeneity.

In terms of textile structural materials, the domestic carbon fiber industry has developed rapidly in recent years, but the production equipment and technology are not advanced enough and the single-line production capacity is low. Therefore, the production cost of domestic products is generally higher than that of imported products. The domestic precursor and carbon fiber have low varieties and specifications, and poor uniformity and stability. A large gap exists between domestic products and imported products in terms of overall performance. The development of domestic carbon fiber application technology lags behind, carbon fiber production enterprises are out of touch with downstream applications, and the downstream market needs to be cultivated and expanded urgently. Breakthroughs in the three-dimensional weaving equipment for high-performance special fibers are still needed. Few large-scale three-dimensional weaving machines for large-scale commercial production are available. Domestic three-dimensional fabric machinery has a low degree of automation. Complex and special-shaped three-dimensional fabrics are still woven with artificial assistance. A single type of stab-resistant fabric exists, and the development path lacks innovation, still being dominated by traditional methods such as coating, laminated composite, and wire/ring addition. The geotechnical material industry faces the problem of repeated construction. The production enterprises are small and scattered and cannot reach the economic scale. Research on the composite function of materials is lacking, and old technologies and materials are mostly used.

In textile composites, domestic raw materials, technology, equipment, and other aspects are inadequate. Compared with the developed countries, China has gaps in the development and preparation technology of special raw materials, industrial concentration, product types and grades, and technological innovation. High-end textile fiber special raw materials mainly rely on imports, raw materials engineering, industrialization capacity is weak, being unable to meet the needs of high-quality industrial development [20]. Basic research on textile flexible materials is also weak. Braiding theory and performance characterization of aramid, polyimide aramid, polyimide and Vectran lack systemability, and the theory and application mechanism of reinforced structure design of textile flexible composite materials also have difficulty supporting industrial development because of incomplete theory. Research on interface theory, multiple composite, and interface control theory of textile flexible composites is deficient, the technology of coating process control and industrialization stability is lagging behind, and the evaluation system and standard of flexible materials have not been established and perfected. These weaknesses make the existing domestic materials unable to meet the comprehensive requirements of complex application service and various environments. In addition, a gap exists between the processing equipment and technology of textile flexible composites in automation, intelligence and information technology, and the international advanced level.

5 Key development directions of advanced base materials for industrial textiles in China

5.1 Main directions of technical research

5.1.1 Nonwoven fiber materials

We should focus on strengthening the basic theoretical research of nonwoven composite and forming; we also need to strengthen the research on key common technologies such as product structure and function design, interface processing, functional finishing, product application evaluation, and functional testing [17]. Active efforts must be made to promote the development and promotion of new nanoscale nonwovens, two-component composite nonwovens, wet-laid nonwovens, such as meltblown, electrostatic spinning, melt blending phase separation, and flash spinning, to improve coating, impregnation, and composite to speed up the development and application of textile-based flexible composite materials.

Intelligent nonwoven production lines with functions such as online monitoring, automatic feedback processing of process problems, full-process intelligent management, and visual operation should be developed. Product application databases and analysis models in filtration, geotechnical, structural enhancement and other fields need to be established. Product design and manufacturing processes must be optimized; product quality, safety, and service life should be improved; and the requirements of different application conditions must be met [17].

The research and development and application of high efficiency, low resistance, long-life, coordinated treatment of harmful substances must also be promoted. High-temperature filter media and economically feasible waste filter media recovery technology need to be functionalized, bag-type dust energy-saving application technology should be developed, and the scope of application must be expanded [17]. The development and application of nonwoven filter materials for air purifiers, vacuum cleaners, and automobile filters should be accelerated. Moreover, the application of geotextile materials with characteristics such as multifunctional suction and drainage, flame retardant and high-strength, intelligent anti-freeze and anti-thaw, high-strength anti-aging, and ecological restoration needs to be promoted.

5.1.2 Textile structure materials

In terms of textile processing equipment manufacturing technology, focus should be directed toward key technologies and equipment such as three-dimensional knitting, weaving, and multiaxial knitting, and special industrial fiber weaving technology and equipment must be developed. Breakthroughs in key technologies need to be made for the preparation of flexible materials for textile structures, and applications in aerospace, construction, and transportation should be expanded.

In terms of the preparation technology of braided materials for safety protection, research on the protection mechanism, the design of protective clothing system, and the evaluation of protection performance should be prioritized to break through the industrialization technology of soft bulletproof and stab-resistant protective textiles and their equipment. The development and application of related products, such as soft bulletproof and stab-resistant equipment, textile-based anti-terrorism and anti-riot equipment, high-temperature protection and rescue equipment, biochemical protection equipment, and family fire-fighting equipment, must be accelerated. A series of textiles, intelligent fire-fighting equipment, emergency rope and net materials, and other products needs to be developed to deal with major epidemic situations.

In terms of the preparation technology of smart textile structure materials, focus should be given to the research and development of wearable device structure materials and flexible conductive textile structure materials, integrated microelectronics, and textile technology. Textiles can also be imbued with intelligent monitoring and other functions, and the production scale of high value-added smart textiles should be expanded.

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In terms of preparation technology of medical textile structural materials, the localization of implantable biomedical textile structural materials should be realized, and medical textiles with independent intellectual property rights and brands, especially high-end medical textiles, must be developed. On the basis of current small-scale tests, breakthroughs in key technologies must be made, pilot-scale demonstration production lines should be established, and industrialization must be achieved.

5.1.3 Textile composites

In improving the molding technology of composite materials, we should focus on numerical control technology, apply mechanization, automation, and intelligence technology to preform molding, and realize the integration of composite design/manufacturing. Theoretical research on fabric structure design, new structure mechanics, and geometry should be strengthened. The combination innovation of traditional molding technology should be conducted, and the appearance contour and mechanical properties of products in three-dimensional space must be optimized.

In the aspect of optimizing the production process of composite materials, we should master the technical principle of liquid composite molding technology, improve the molding process of composites, and break through the technology of hot-pressing predetermined type and high-precision mixed injection. To strengthen the research on main bearing structure composites, we should master the technology of high pressure-resin transfer molding, compression-resin transfer molding, and thermoplastic-resin transfer molding, and realize the engineering application in automobile bodies, aircraft shells, and large ships.

In improving composite material production equipment, a highly integrated process automation production line can be established, and integrated equipment design and manufacturing technology must be mastered. Digital intelligent production equipment and testing equipment needs to be developed to achieve composite design/manufacturing integration, which is integral to molding integration ability.

In the aspect of the overall design technology of lightweight and high-strength textile flexible material structure, material innovation design, comprehensive performance analysis, and modification optimization research should be conducted according to different material categories to solve a series of technical problems in the mass industrial production of textile flexible materials. Other important tasks are to study the relationship between materials, structure, and properties; form a perfect design theory and manufacturing process system; develop a complete set of molding dies and equipment; and establish practical test methods and standards for connection processes [20].

In terms of technology control and stability of wide-width multilayer coating, the key technology of multilayer composite structure and functional hybrid coating can be solved to control the internal and surface defects of coating, and the stability of coating process and process control can be improved to meet the requirements of batch production.

An intelligent complete set of super thickness spacing (more than 300 mm) three-dimensional spacer fabric must be developed along with ultra-thickness special equipment; the latter is developed to break through the technology of intelligent control of super thickness spacing guide bar translation control, intelligent swing control, intelligent real-time dynamic control tension compensation, and intelligent electronic transversal, among others, to meet the constant tension and high-precision control requirements of super-wide spacing feeding, knitting, pulling, and winding.

5.2 Key directions of product development

Comprehensive research and judgment determined that the overall development goal of advanced base materials for industrial textiles in China's textile industry is to build a rationally laid-out and dynamic industrial technology innovation system, form a batch of original innovation results with independent intellectual property rights, and enhance the industry's continuous innovation capability. In the key direction of high-end industrial textiles such as nonwoven fiber materials, textile structural materials, and textile composites, we will cultivate internationally competitive backbone enterprises and a group of specialized and excellent enterprises to strengthen the industrial foundation and the industrial chain weaknesses. Thus, the proportion of middle- and high-end products in China will be significantly increased. The green and intelligent level of textile materials can reach the international advanced level, thereby driving the textile industry into the middle and high ends of the value chain.

A catalog of key products of advanced base materials for industrial textiles for 2025 and 2035 is shown in Table 2.

Table 2. Key product catalog of advanced base materials for industrial textiles in China.

Species	Key product name
Nonwoven fiber materials	Two-component spunbond nonwoven material
	Electret nonwoven air filter material with high efficiency, low resistance, and durability
	Multi-die melt spinning composite nonwoven fabric
	High-temperature-resistant nonwoven filter material
	Micro-nanofiber composite nonwoven filter material
	Washable wipes
Textile structure materials	Carbon fiber fabric
	Three-dimensional braided materials
	Stab-resistant materials
	Grid structure geotechnical materials
	High-strength ropes
Textile composites	Carbon fiber-reinforced composites
	Aramid fiber-reinforced composites
	Silicon carbide fiber-reinforced composites
	Functional flexible canopy materials
	Lightweight airship envelope skin and inflatable structure material
	Medical mesh structure composite patch material

6 Countermeasure and suggestion

6.1 Strengthen the top-level planning of industrial development

A departmental coordination mechanism needs to be established, and top-level design and overall planning need to be improved. Moreover, the macro-guidance and information guidance for the industrial development of advanced base materials for industrial textiles must be strengthened. Advice needs to be given for industrial policies, industry planning, and major projects, and advantageous resources must be concentrated to promote research, development, engineering, industrialization, and application. A well-structured and stable team of high-level industrial development strategy researchers should be established to track and evaluate the development status and implementation of the plan through continuous, in-depth, and systematic research. The plan should be adjusted in a timely manner and improved continuously to provide reliable guidance for the macro decision-making of relevant industries in China, as well as the business activities of production enterprises, financial investment institutions, and scientific research institutions.

6.2 Strengthen the construction of national scientific and technological innovation support system

High-end scientific and technological resources need to be integrated. Other steps are to optimize the innovation operation mechanism, establish a national textile material innovation center, and strive to fundamentally solve the following problems: the homogeneity and fragmentation of innovation resources are related to the long-term development of the industry and the lack of basic and public welfare research for international competition, the low efficiency of the core industries in major key technology innovation, and the lack of core hubs for the textile industry value chain and value network [21]. Focus must be directed toward improving the technical level and industrial capabilities of key materials for both military and civilian use, and the layout of key laboratories and engineering technology centers needs to be improved to establish a solid foundation for original innovation. The guiding role of government funds must be maximized, and policies and measures need to be improved. Efforts must be made to attract venture and industrial funds, and innovation in key technological fields must be ensured.

6.3 Build a number of specialized and excellent enterprises

Related enterprises should be encouraged to improve, and enterprise technology and management innovation must be implemented. Specialized high-performing enterprises need to be given support to extend the industrial chain. The strengthening of key basic materials needs to be given attention as well, along with the core basic parts (components), advanced basic technology, and industrial technology foundation for the four industrial bases field. The industrial foundation and industry chain short board need to be strengthened, and the international competitive advantage of the industry must be cultivated. In addition, more benchmarking enterprises need to be built, and a

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number of “single champion”, “invisible champion”, and “small giant” enterprises should be formed. At the same time, we should pay attention to broadening the channels of international cooperation, combine the construction of the Belt and Road Initiative, and promote in-depth exchange and extensive cooperation among the talent team, technical capital, standard, patent, and management experience in the new materials industry.

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